Raytheon

Air Traffic Management System Development and Integration (ATMSDI)

DAG-TM Test Plan

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FINAL DRAFT

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Prepared for

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1. INTRODUCTION

1.1 Background

1.1.1 Distributed Air/Ground Traffic Management

Distributed Air/Ground Traffic Management (DAG-TM) is a proposed solution for expanding airspace capacity limits. DAG-TM alters the roles and responsibilities of the stakeholders to permit more user-preferred routing, increased flexibility, increased system capacity, and improved operational efficiency. DAG-TM is based on the fundamental premise that all system participants can be information suppliers and users, thereby enabling collaboration and/or distribution at all levels of traffic management decision-making. This new environment will achieve successful operation through new human-centered operational paradigms enabled by procedural and technological innovations. These innovations include:

- Decision support tools (DST)
- Information sharing
- Communication, navigation, and surveillance (CNS)/air traffic management (ATM) technologies.

The present study investigates the following three DAG-TM concept elements: *En Route Free Maneuvering*, *En Route Trajectory Negotiation*, and *Terminal Arrival: Self-Spacing for Merging and In-Trail Separation*.

1.1.1.1 Concept Element 5

In CE 5, *En Route Free Maneuvering*, appropriately equipped aircraft accept the responsibility to maintain separation from other aircraft while exercising the authority to freely maneuver in en route airspace. Free maneuvering aircraft have the authority to establish new user-preferred trajectories with the restriction that new trajectories conform to local traffic flow management (TFM) constraints and do not create traffic conflicts. The flight crew's role is to avoid conflicts with other aircraft or airborne hazards (e.g., special use airspace, weather) by maintaining separation while meeting a required time of arrival (RTA). Free maneuvering aircraft have DSTs that enable situation awareness, allow flight crews to maintain separation from other aircraft without air traffic service provider (ATSP) assistance, and provide trajectory planning capabilities (Phillips, 2000).

1.1.1.2 Concept Element 6

CE 6, *En Route Trajectory Negotiation*, focuses on real-time collaboration among the DAG-TM stakeholders (flight crews, ATSP, Airline Operations Center [AOC]) for initiating trajectory changes. A trajectory change may be initiated by any of the stakeholders, but responsibility for separation remains with the ATSP (Couluris, 2000). The flight crew, while given authority to negotiate trajectory changes, must conform to TFM constraints defined by the ATSP. Implicit to the concept is the coordination between sector controllers for efficient, integrated flight planning. This requires a trajectory-oriented approach that will enable controllers to plan and coordinate trajectories across sector boundaries while maintaining separation and conforming to TFM constraints. The AOC may specify airline constraints and preferences (related to fuel efficiency, scheduling, or passenger comfort) and may initiate both long- and short-term trajectory changes. In the current concept description, the AOC-defined constraints and preferences are transmitted to the ATSP and flight deck (FD).

1.1.1.3 Concept Element 11

CE 11, *Terminal Arrival: Self-Spacing for Merging and In-Trail Separation*, is intended to increase terminal area throughput by providing flight crews and ATSPs with a method for reducing in-trail separation (Sorensen, 2000). Time-based spacing, rather than distance-based, allows for spacing compression as aircraft speeds decrease throughout the approach. Appropriately equipped aircraft entering an arrival stream are assigned an in-trail spacing interval behind a lead aircraft. The ATSP is responsible for specifying the interval and lead aircraft, as well as monitoring traffic flow and maintaining separation. Flight crews receive traffic intent information through airborne DSTs that support the merging and spacing operations.

1.2 Purpose and Rationale

The purpose of the DAG-TM activities for September 2002 is to evaluate the three concept elements against a baseline environment. The evaluation will focus on the operational benefits and the viability of each concept element.

2. METHOD

2.1 Simulation Facilities

The DAG-TM simulation environment is distributed among different facilities and laboratories at NASA Ames Research Center. The three main laboratories involved are the:

- Airspace Operations Lab (AOL) providing aircraft target generation, Air Traffic Control (ATC) and Management stations augmented with Center TRACON Automation System (CTAS) decision support tools, and the Multi Aircraft Control System (MACS),
- Flight Deck Display Research Laboratory providing mid-fidelity desktop simulators equipped with Cockpit Displays of Traffic Information (CDTI), and
- Crew Vehicle Systems Research Facility (CVSRF) providing the Advanced Concepts Flight Simulator (ACFS), a high fidelity full mission flight simulator.

Figure 1 illustrates the DAG-TM simulation architecture that will be employed. All major components of the simulation are connected via the Aeronautical Datalink and Radar Simulator (ADRS) processor. The ADRS functions as the communication management and data distribution hub. It also simulates a datalink system by receiving datalink information from simulated aircraft or ground facilities in different formats and then delaying, converting, and forwarding the information as required. See Prevot, Palmer, Smith, and Callantine (2002) for a detailed description of the DAG-TM simulation environment at NASA Ames.

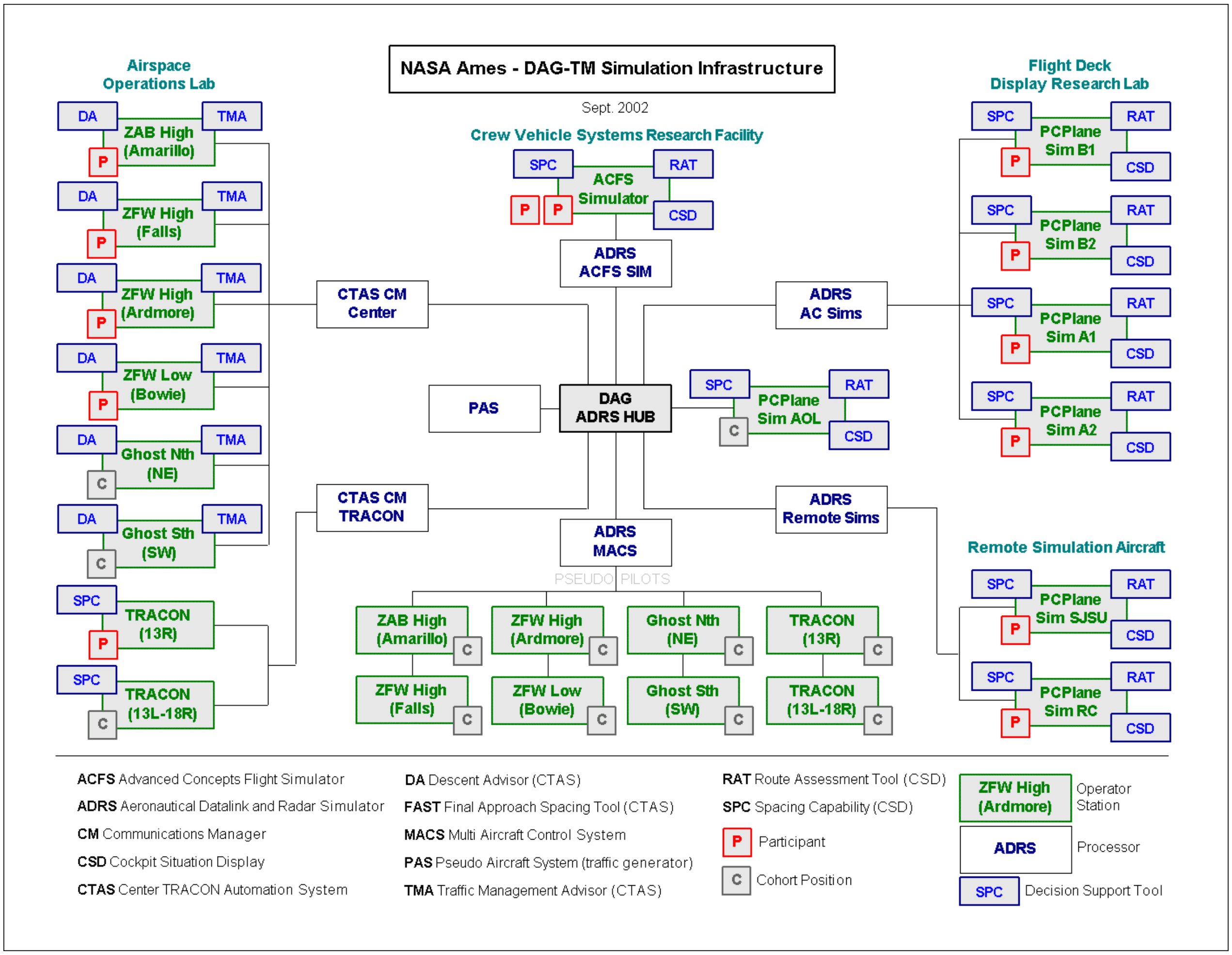

Figure 1. NASA Ames Distributed Air-Ground Simulation Architecture.

2.1.1 Airspace Operations Laboratory

The AOL is a multi functional simulation laboratory. It controls the overall progress of the simulation, hosts the air traffic control and management facilities, and pilots the majority of the aircraft throughout the scenario. The air traffic control facilities consist of several controller workstations distributed through two control rooms (Figure 2). Each workstation is configurable to an en route sector, center airspace, or terminal radar approach control (TRACON) airspace and equipped with air-ground/ground-ground communications lines. Workstations use modified plan-view graphical user interfaces (PGUI) that are part of the CTAS. MACS control stations are situated in a separate room within the AOL. See Section 2.2.1.1 for a description of the MACS.

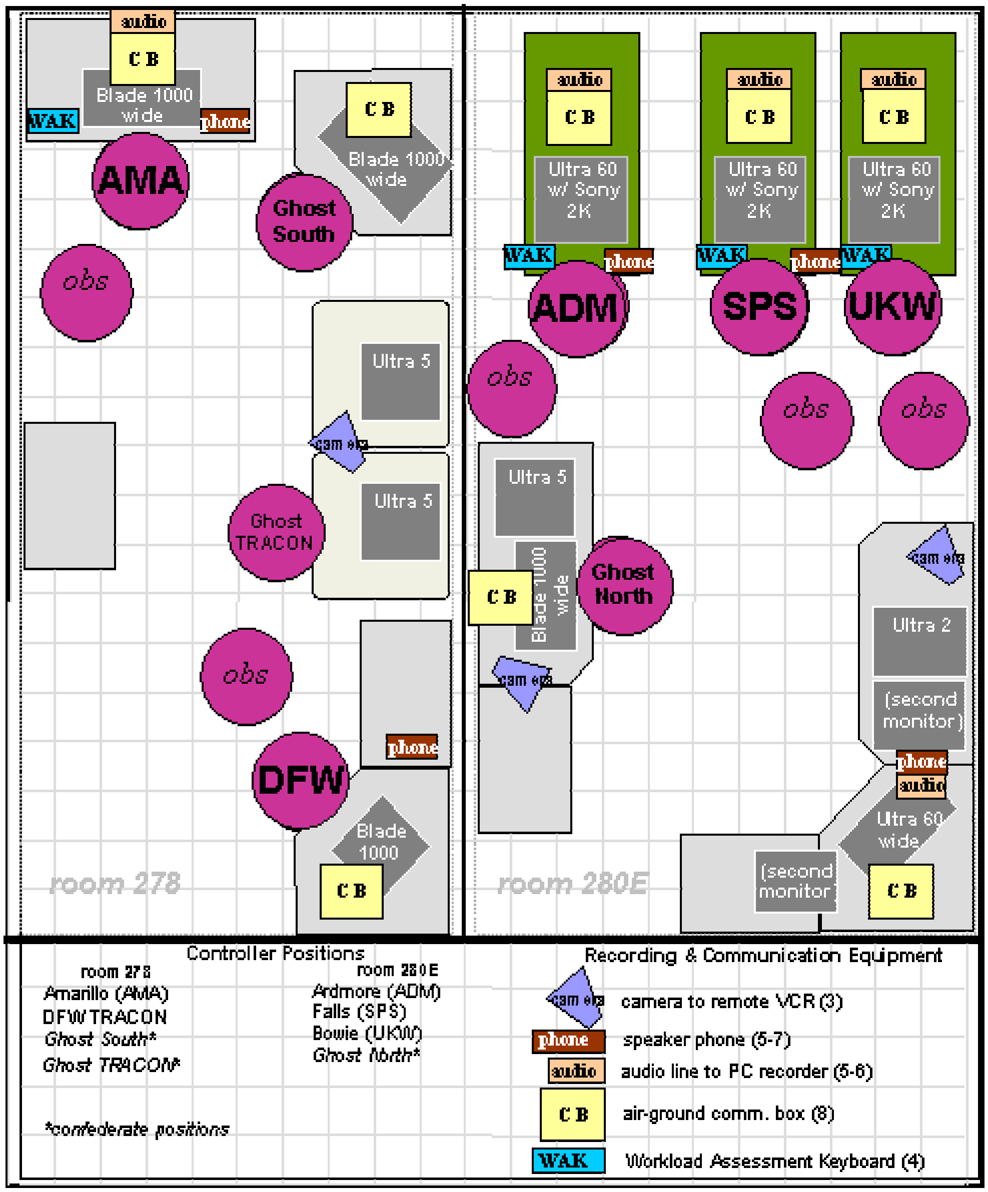

Figure 2. Airspace Operations Laboratory (AOL) layout.

Figure 2 shows the AOL layout for the present study. Fort Worth Center (ZFW) positions (Ardmore, Wichita Falls, and Bowie) and the Ghost North position are located in room 280E. Amarillo, Dallas/Fort Worth (DFW) TRACON, and Ghost South positions are located in room 278.

The communication system includes air-ground communication units at each controller position. The communication units provide two-way voice communications between controllers and pilots. The communication equipment may also be used for ground-ground voice communications with other controllers. Conventional telephone lines provide a second means for ground-ground voice communications. Telephones are located either at individual positions or are shared between two positions.

The AOL is equipped with several types of recording equipment. Cameras, connected to a remote videocassette recorder (VCR), are used to capture the activities of subject controllers. An audio recording system is capable of capturing all voice communications that occur via the communication boxes. Workload Assessment Keyboards (WAK) are used to record real-time workload ratings.

2.1.1.1 Multi Aircraft Control System

The MACS is a mid-fidelity, multi aircraft control station (Figure 3). The display provides several flight deck components:

- Mode control panel (MCP)
- CDTI
- Primary flight display (PFD)
- Flight Management System (FMS) route and vertical navigation (VNAV) panels
- Self-spacing panel.

The MACS also maintains a list of all aircraft that are controlled from the station and a "to do" list that keeps track of those aircraft for which an operator action, like a radio check-in or a lower altitude setting, is expected. MACS provides reminders to the operators when actions must be taken by highlighting aircraft in list windows (see Figure 3).

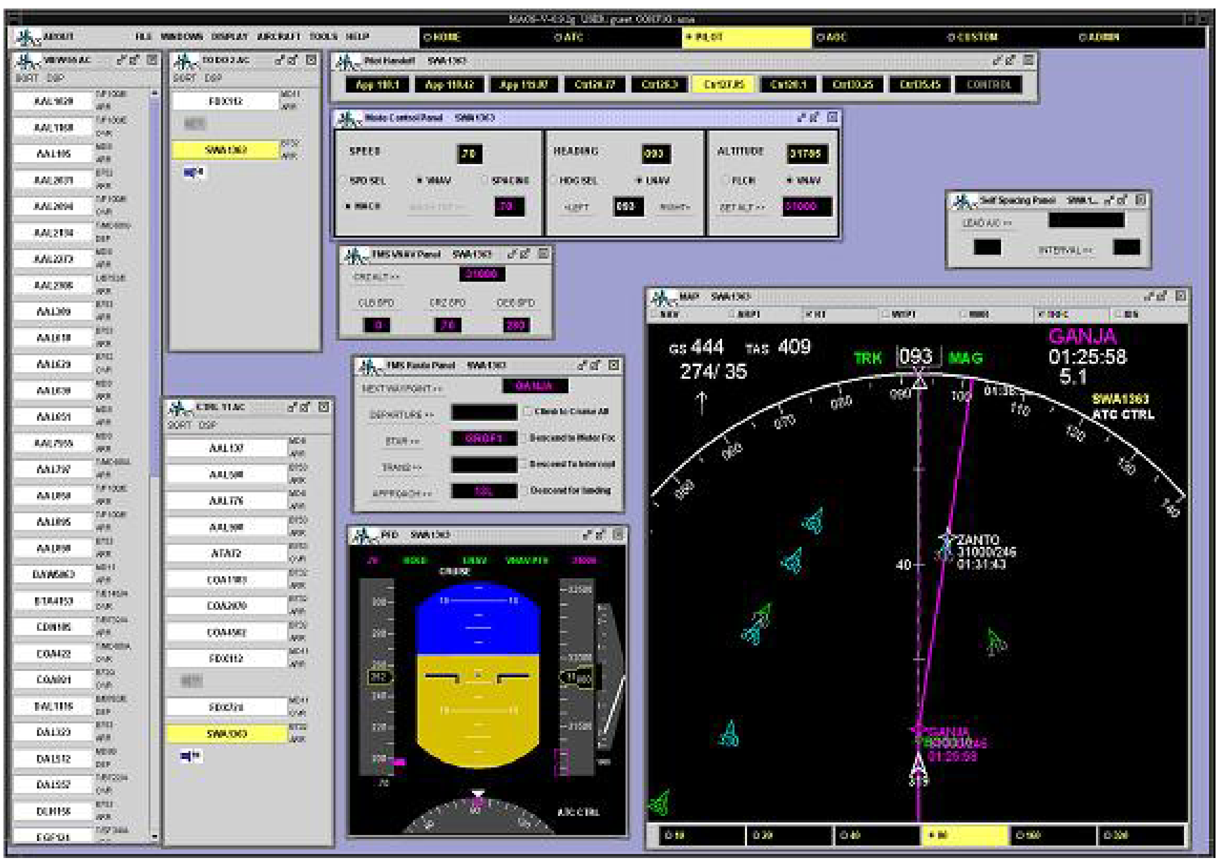

Figure 3. The Multi Aircraft Control System Interface.

The operator can enter basic autopilot commands on the MCP and can enter lateral navigation (LNAV) and VNAV commands on the FMS Route Panel and FMS VNAV Panel, respectively. A Pilot Handoff Panel allows the operator to hand the aircraft to another MACS operator controlling aircraft on a different frequency.

2.1.2 Flight Deck Display Research Laboratory

Flight Deck Display Research Laboratory houses the PCPlane desktop simulators. PCPlane is a mid-fidelity, single-aircraft flight deck simulator with a specialized CDTI display and custom datalink interfaces. The lab provides the capability for multiple simulation sites to participate as additional flight decks in traffic scenarios. This capability increases the potential for free-maneuvering aircraft participants as required for DAG-TM research.

2.1.2.1 PCPlane Flight Deck Simulator

PCPlane, developed at NASA Langley Research Center, is a PC-based simulator of a Boeing 757 flight deck (Figure 4). The simulator includes a MCP, PFD with CDTI (see Section 2.2.2.2), FMS, and datalink window. It interfaces to the ADRS.

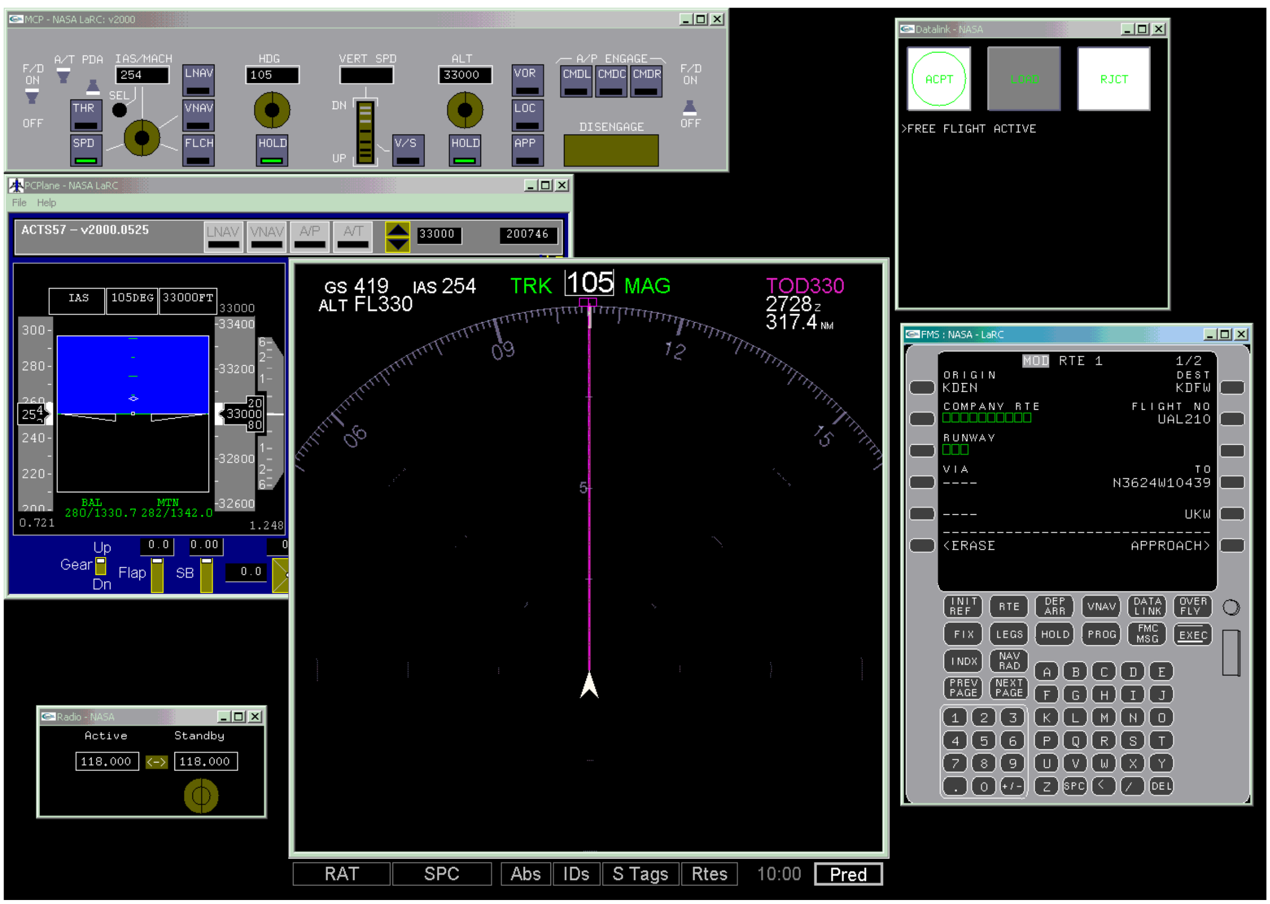

Figure 4. PCPlane Flight Deck Simulator.

2.1.2.2 Cockpit Display of Traffic Information

The CDTI, developed at NASA ARC, allows the flight crew to operate within a distributed environment by providing several specialized flight management tools:

- Primary alerting system (PAS)
- Route analysis tool (RAT)
- Terminal area approach spacing tool

The PAS alerts the flight crew to potential traffic conflicts along the current flight path. It is designed to detect any loss of separation (LOS) between ownship and another aircraft. PAS provides three levels of conflict alerting. The RAT allows the flight crew to develop and test potential flight plan changes before they are actually implemented (Figure 5). The approach spacing tool allows the flight crew to self-space behind a lead aircraft by selecting the lead and a time or distance to follow. The appropriate speed to achieve/maintain the desired spacing is computed and indicated through display symbology (Figure 6). In-trail spacing uses an airborne inter-arrival spacing algorithm developed by NASA Langley Research Center to aid pilots in maintaining a time-based spacing interval (Abbott, 2002). See Raytheon Air Traffic Management System Development and Integration (ATMSDI) Team (2002) for a detailed description of the NASA Ames CDTI.

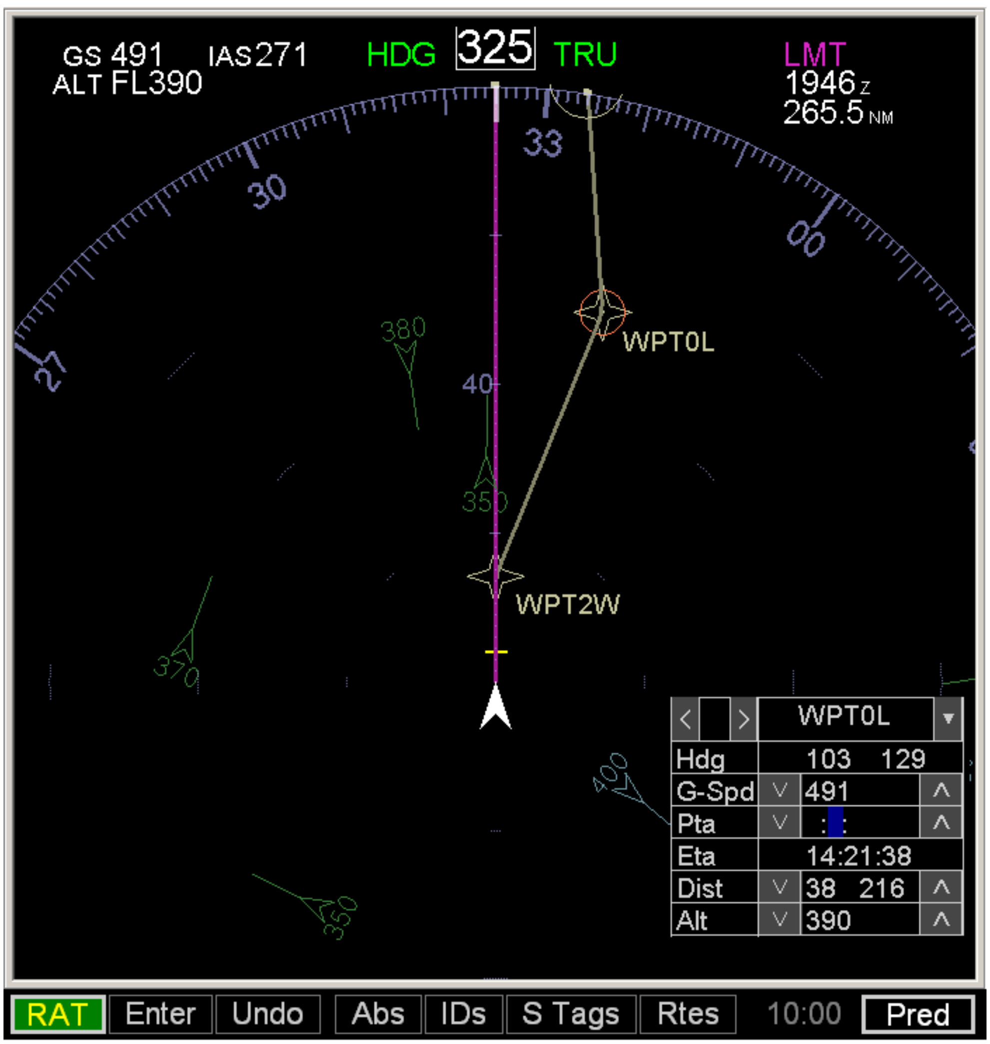

Figure 5. CDTI with Route Analysis Tool Engaged.

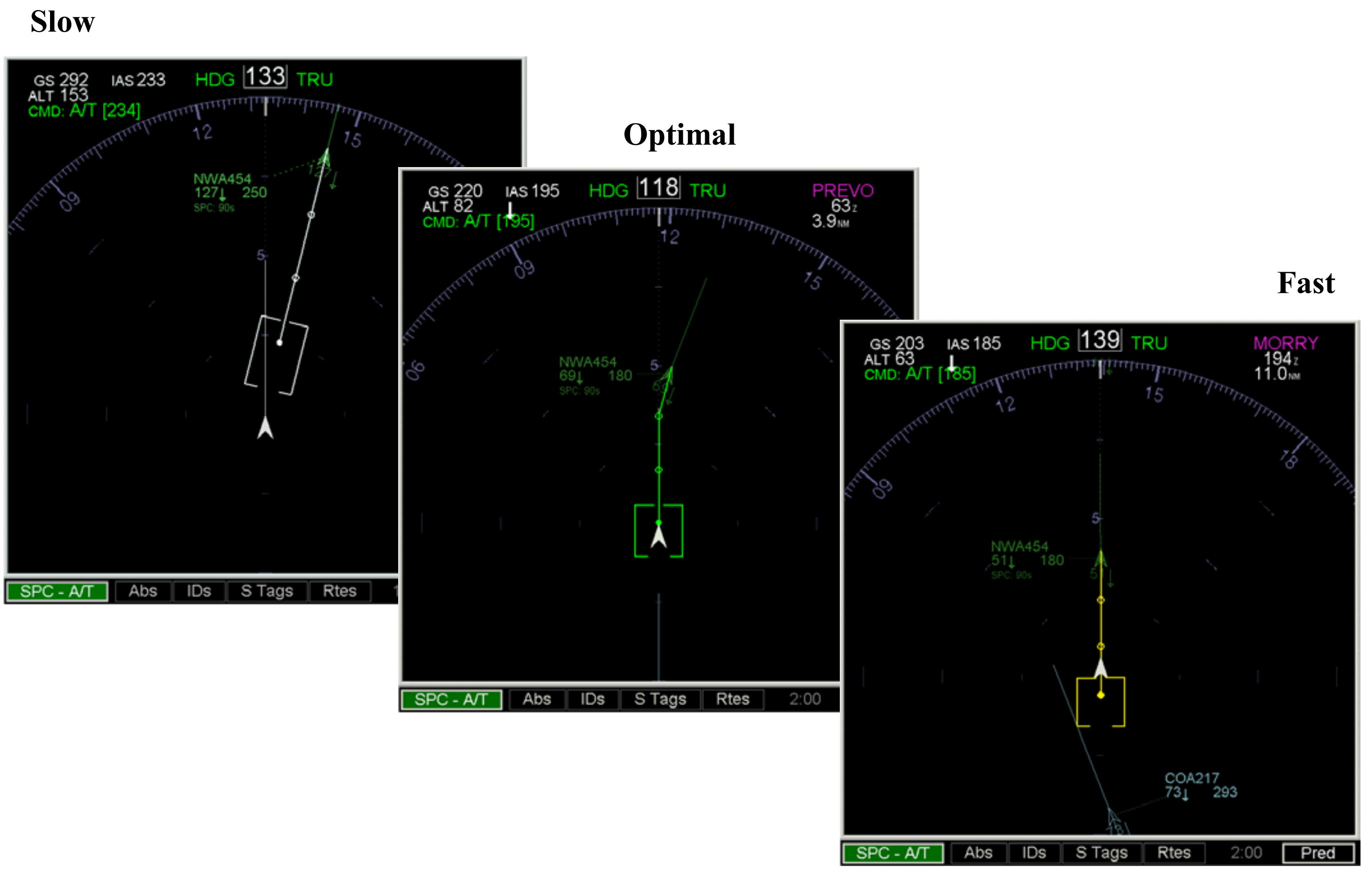

Figure 6. CDTI with Approach Spacing Tool Engaged.

2.1.3 Crew Vehicle Systems Research Facility

The CVSRF houses the ACFS that is used in the DAG-TM simulation environment. It is a 6-degree of freedom full mission flight simulator equipped with Future Air Navigation System (FANS)-type datalink capabilities and CDTIs on both the captain's and the first officer's position. CDTI functions and capabilities are identical to those of the PCPlane simulator (see Section 2.2.2.1).

2.2 Participants

Because of the distributed nature of the tasks involved in this study, both subject participants and support participants will be included. Data will be collected from subject participants only. Support participants will play the roles of National Airspace System (NAS) users to populate the scenarios.

2.2.1 Subject Participants

The subject participants will consist of five ATSPs and eight licensed pilots. An ATSP team composed of full performance level controllers will work four en route sector positions and one

TRACON position. These controllers already have some DAG-TM experience from participating in previous demonstrations and technical meetings.

All pilots will be air transport rated and have glass cockpit experience. One pilot team (first and second officer) will fly the ACFS. The six other pilots will fly the PCPlane desktop flight deck stations.

2.2.2 Support Participants

The support participants, those who will participate in the experiment on behalf of the experimenters but are not test subjects, will consist of three confederate controllers and 10 pseudo-pilots. The three controllers (retired ATSPs) will work two adjacent en routes sector positions and a TRACON position. The pseudo-pilots (GA licensed and/or student pilots) will work the MACS control stations. Each pseudo-pilot, or pair of pseudo-pilots, will fly all aircraft within a designated airspace (which corresponds to sector controller airspace).

2.3 Operational Environment

2.3.1 Airspace

The simulation traffic scenarios occupy the airspace that handles northwest arrivals into the Dallas/Fort Worth Airport (DFW). The airspace encompasses several en route sectors in ZFW and a portion of the Albuquerque Center (ZAB) airspace (Figure 7). DFW and Love Field (DAL) arrivals transition to the DFW TRACON. Transition occurs at the TRACON boundary fix, BAMBE for DFW arrivals and GREGS for DAL arrivals. The UKW merge point feeds both boundary fixes. BAMBE is the meter fix for all DFW arrivals in this simulation. (See Appendix B for DFW arrival charts and surface map.)

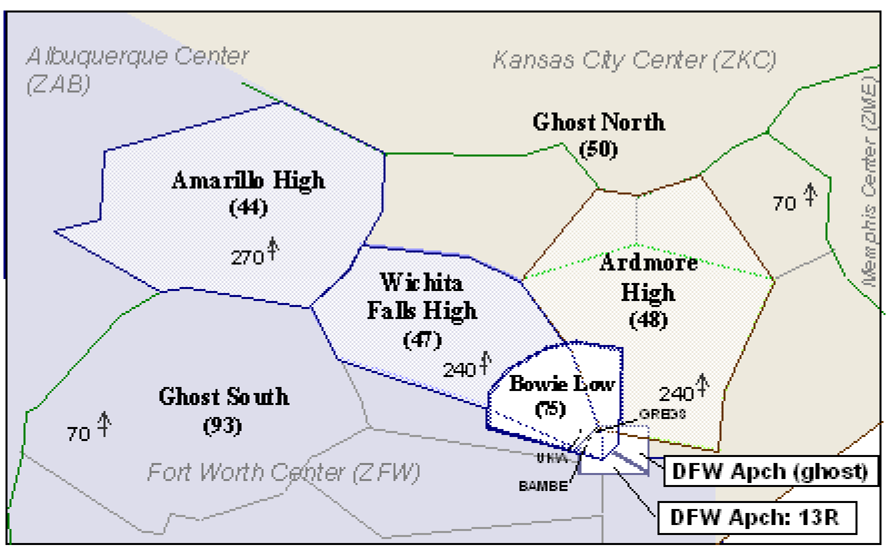

Figure 7. Simulation Airspace.

The five airspace sectors that will be staffed by subject controllers:

- Amarillo a high altitude sector within ZAB airspace

- Wichita Falls — a high altitude sector within ZFW airspace that handles a large portion of arrivals to DFW
- Ardmore — a high altitude sector* within ZFW airspace that typically handles a mix of DFW arrivals/departures and over-flights
- Bowie — a low altitude sector within ZFW airspace that handles northwest arrivals to DFW. The merge point (UKW) and northwest TRACON boundary fix (BAMBE) are within Bowie airspace.
- TRACON — Terminal Radar Approach Control for DFW RW13R.

* The Ardmore sector's northern boundary has been modified for this study, extending north to the ZFW/ZKC Center boundaries. This was done to enable arrival aircraft from the north to enter one of the test sectors earlier in the scenario.

Confederate controllers will staff three other positions:

- Ghost North — a “super” en route (high/low altitude) sector that includes the northern part of ZFW and a southern portion of the Kansas City Center (ZKC)
- Ghost South — a “super” en route (high/low altitude) sector that includes the southwestern part of ZFW and an eastern portion of ZAB
- Ghost TRACON — a Terminal Radar Approach Control position that handles traffic for DFW RW18R, DFW 13R Tower and DAL RW 13L.

2.3.2 ATSP Tools

En route and TRACON controllers are provided with a variety of CTAS tools, such as the Traffic Management Advisor (TMA) and the Descent Advisor (DA). The TMA optimizes the arrival flow by scheduling aircraft on a first-come, first-served basis. Aircraft with earlier estimated times of arrival (ETA) are assigned earlier scheduled times of arrival (STA). The TMA scheduler is set up, for this study, to provide a minimum of 7 miles-in-trail spacing at the meter fix. At BAMBE, with an 11,000 foot and 250 knot crossing restriction, this translates to roughly 82 seconds minimum spacing between aircraft. The DA provides speed advisories and supports manual route planning as well as calculating RTAs.

Controller workstations include:

- Controller PGUI
- CTAS DSTs
  - TMA with ETA and STA capability
  - Conflict detection
  - Trial (route) planning
  - DA with RTA capability
- Datalink capability
- Control exchange (autonomous to managed and vice versa) capability

- Arrival spacing capability (time-based)

In order to support DAG-TM CE 11, airborne self-spacing functionality is available to the TRACON controller through the display of actual and advised spacing intervals. History circles support the airborne self-spacing function by indicating the desired position of a trailing aircraft behind a lead aircraft.

2.3.3 Summary of Operational Parameters

There are several parameters that define the operational environment. These parameters (e.g., an aircraft's equipage and the level of distributed control) determine the extent to how each aircraft will operate within a specified airspace. Table 1 summarizes of the operational parameters. In addition, each of these parameters are further explained in the following four sections; Aircraft Equipage (Section 2.3.4), Level of Distributed Control (Section 2.3.5), DAG-TM Capabilities (Section 2.3.6), and Modes of Operation (Section 2.3.7).

Table 1. Summary of Operational Parameters.

Modes of Operation	Aircraft Equipage	En Route Airspace		Terminal Airspace	
		Level of Control	DAG-TM Capabilities	Level of Control	DAG-TM Capabilities
Baseline	Equipped	Managed	None	Managed	None
	Unequipped	Managed	None	Managed	None
CE 6 & 11	Equipped	Managed w/ negotiation authority	Trajectory negotiating	Managed w/ self-spacing authority	In-trail spacing
	Unequipped	Managed	None	Managed w/ self-spacing authority	In-trail spacing
CE 5 & 11	Equipped	Autonomous	Free maneuvering	Managed w/ self-spacing authority	In-trail spacing
	Unequipped	Managed	None	Managed w/ self-spacing authority	In-trail spacing

2.3.4 Aircraft Equipage

Pilots participating in the study will be provided with tools that allow them to operate in a DAG-TM-type environment. A mix of equipped and unequipped aircraft will fly in the airspace. There will be approximately 90 unequipped and 7 equipped aircraft included in each one-hour simulation run.

2.3.4.1 Equipped Aircraft

Equipped aircraft are provided with technology necessary to 1) create and execute user-preferred trajectory changes within en route airspace, 2) detect and resolve potential traffic conflicts, and 3) maintain self-spacing within terminal airspace. Equipped aircraft possess the following:

- FMS
- CDTI with
  - Aircraft intent information

    - Conflict detection with manual resolution
    - Route planning
    - RTA
    - Precision descent procedure (This is a procedure flown with conventional FMS VNAV)
    - Arrival spacing capability (time-based)
- Automatic Dependent Surveillance-Broadcast (ADS-B)
- Controller Pilot Data Link Communications (CPDLC)

2.3.4.2 Unequipped Aircraft

Unequipped aircraft simulate current day capabilities with a few additional ones. Unequipped aircraft possess the following:

- FMS
- CDTI with
    - Traffic Alert and Collision Avoidance System (TCAS)
    - RTA
    - Arrival spacing capability (time-based)
- ADS-B
- CPDLC

2.3.5 Levels of Distributed Control

The level of distributed control refers to the delegation of control between the ATSP and the flight crew, namely, who maintains separation responsibility. It also defines the extent to which the flight crew can self-manage their flight. For example, the flight crew of an autonomous aircraft is permitted to make flight plan changes without ATSP approval.

2.3.5.1 Managed

An aircraft is managed if the controller retains separation responsibility for that aircraft. Unequipped aircraft will be managed at all times. An equipped aircraft will be managed if 1) the flight crew has not yet been given autonomous control or 2) the flight crew of an autonomous aircraft requests (and the controller accepts) that ATC resume separation responsibility. In the case of a potential conflict between a managed and autonomous aircraft, the autonomous aircraft and the controller acting on behalf of the managed aircraft follow specified flight rules.

2.3.5.2 Managed with Negotiation Authority

Managed with negotiation authority follows the same rules as managed with one exception. The flight crews of equipped aircraft are given authority to negotiate trajectory changes (Section 2.3.6.1). All trajectory changes must be submitted to the ATSP for approval before the change can be implemented and negotiation can only take place while in en route airspace.

2.3.5.3 Managed with Self-Spacing Authority

Managed with self-spacing authority follows the same rules as managed with one exception. Upon entering terminal airspace, the flight crews of both equipped and unequipped aircraft are given the authority to implement in-trail spacing along a FMS arrival route (Section 2.3.6.3). Each aircraft's flight crew is responsible for maintaining the specified temporal spacing. The responsibility of maintaining the separation minimum is always that of the ATSP. Self-spacing can only take place while in terminal airspace.

2.3.5.4 Autonomous

An aircraft is autonomous and allowed to free maneuver (Section 2.3.6.2) if it is appropriately equipped and has been granted the authority to execute user-preferred trajectory changes without requesting ATC clearance. The flight crew of an autonomous aircraft has the responsibility of maintaining the separation minimum and resolving potential traffic conflicts while following the rules-of-the-road (see Section 2.3.8). Autonomous control will only be granted while in en route airspace.

2.3.6 DAG-TM Capabilities

2.3.6.1 Trajectory Negotiating

The flight crew generates a user-preferred trajectory modification that is data-linked to the ATSP. The ATSP reviews the request, either accepting or rejecting it, and data-links the response back to the flight crew. If accepted, the flight then instructs the aircraft's FMS to initiate the trajectory. On-board automation broadcasts the modified trajectory using ADS-B to the ATSP and to other aircraft. Trajectory modifications are expected not to create near-term conflicts with other aircraft in the vicinity.

The ATSP provides the flight crews with local TFM constraints such as RTA, altitude, speed, or spacing restrictions, and may up-link ATSP-generated clearances.

2.3.6.2 Free Maneuvering

The flight crew generates user-preferred trajectory modifications and instructs the aircraft's FMS to initiate the trajectory. On-board automation broadcasts the modified trajectory using ADS-B to the ATSP and to other aircraft. The flight crew has the responsibility to ensure that trajectory changes do not generate near-term conflicts with other aircraft in the vicinity. A conflict detection tool provides predicted conflict alerts that require the flight crew to respond accordingly, either taking evasive action or allowing the intruder aircraft to maneuver. The manner in which a traffic conflict is resolved is determined by the rules-of-the-road.

2.3.6.3 In-Trail Spacing

Upon entering terminal airspace, the flight crew flies along a structured arrival route behind a designated lead aircraft. The ATSP is responsible for assigning the lead aircraft and the temporal spacing interval. The flight crew is responsible for maintaining the assigned spacing interval. DSTs will allow the flight crew to monitor their spacing performance and compensate for spacing variations within the arrival stream. The lead aircraft will always be in the same arrival stream.

2.3.7 Modes of Operation

This study will investigate three modes of operation – a baseline mode and two DAG-TM modes. The Baseline mode is designed to equate to current-day capabilities and tools. In all modes of operation, controllers will be attempting to deliver aircraft to the BAMBE meter fix at the TMA scheduled times.

2.3.7.1 Baseline

The baseline condition is designed to represent present-day airspace operations with the addition of the TMA. Using current standard operating procedures (SOP), aircraft travel through en route airspace towards an arrival airport. All aircraft have ADS-B capability, which permits the display of proximal traffic on the CDTI display. In this mode of operation the pilots can use the CDTI only for situation awareness. They transition to TRACON airspace and land with the assistance of ATSPs. All aircraft, whether equipped or unequipped, are managed and ATSPs are responsible for maintaining separation.

Technologies

Controller Workstations

- CTAS TMA (only sequence list and delay information)

Unequipped Aircraft

- As defined in Section 2.3.4.2, except…
- No arrival spacing capability
- No CPDLC
- No RTA capability

Equipped Aircraft

- All equipped aircraft function as unequipped aircraft

Standard Operating Procedures

- Current-day SOPs
- ATSP are expected to conform to RTAs
- All aircraft fly FMS Transition in TRACON

2.3.7.2 DAG-TM Trajectory Negotiation (CE 6 & CE 11)

Aircraft fly en route towards an arrival airport. All aircraft are under the control of the ATSP and have data-linked meter fix times. A few aircraft are provided with the tools that enable them to modify flight path trajectories during the en route phase. These aircraft have the capability to send and receive trajectory requests to and from the ATSP. The nature of the traffic flow problem will likely produce delays. These delays could result in aircraft being taken off their preferred routes. Less than optimal routing may motivate flight crews' of equipped aircraft to request alternative trajectories.

One or more streams of traffic merge at the TRACON meter fix and enter terminal airspace. ATSP can issue a limited delegation clearance to both equipped and unequipped aircraft. The clearance includes a time-based spacing interval and lead aircraft to space behind. As many

DFW arrivals as possible will land on RW13R, with Runway 18R available for excess aircraft. A few aircraft will be routed to DAL RW13L. ATSP can issue a limited delegation clearance to space behind a lead aircraft. Using flight deck DSTs, the flight crews identifies the lead aircraft and then uses the assigned spacing interval to self-space behind it.

The TRACON controllers monitor the air traffic situation and use a ground based DST to monitor conformance and assign spacing intervals. The controller manages aircraft to provide sequencing and spacing guidance while providing separation assurance for all aircraft.

Technologies

Controller Workstations

- As defined in Section 2.3.2, except…
- No control exchange capability

Unequipped Aircraft

- As defined in Section 2.3.4.2

Equipped Aircraft

- As defined in Section 2.3.4.1

Standard Operating Procedures

- ATSP maintains separation responsibility for all aircraft at all times
- ATSP attempts to maintain lateral trajectories by first considering speed and altitude changes
- Only equipped aircraft may request trajectory changes
- All trajectory change requests must be conflict-free
- ATSP has the authority to reject any trajectory change request
- RTA and speed advisories are automatically up-linked to arriving equipped aircraft
- Equipped aircraft are responsible for meeting their RTAs (± 15 seconds) and are expected to stay on their 4D trajectories
- Modifications to speed (by equipped aircraft) to maintain RTA do not need concurrence
- Speed clearances from the ATSP supercede the current up-linked RTA
- All aircraft follow the precision descent procedure
- ATSP may assign spacing interval and lead aircraft upon entry into terminal airspace
- Flight crew has the authority to reject the spacing clearance
- All aircraft fly FMS Transition in TRACON

2.3.7.3 DAG-TM Free Maneuvering (CE 5 & CE 11)

Using flight deck DSTs, flight crews of equipped aircraft have the authority to execute flight plan changes without ATSP review. Autonomous aircraft are responsible for maintaining separation from traffic. Autonomous aircraft are required to use cockpit DSTs for conflict detection and resolution while meeting RTAs and conforming to the rules-of-the-road (see

Section 2.3.8.1). Limited exchange of control between equipped aircraft and ATSP may occur. All aircraft will transition to managed TRACON airspace.

The en route controllers monitor the air traffic situation and use ground based DSTs to compute trajectories and broadcast RTAs for terminal airspace transition. Controllers manage unequipped aircraft (and equipped aircraft if requested) and provide separation from autonomous and other managed aircraft as well as airspace hazards. The rules-of-the-road define the responsibilities of controller and flight crew for resolving traffic conflicts. The low altitude en route controller is responsible for transitioning free maneuvering aircraft from autonomous to managed control. Entry of autonomous aircraft in terminal airspace will adhere to the procedures for transitioning (see Section 2.3.8.3).

As with *DAG-TM Trajectory Negotiation* mode, one or more streams of traffic merge at the TRACON meter fix and enter terminal airspace. The TRACON controller manages the arrival stream through sequencing and spacing guidance (i.e., spacing interval and lead aircraft) while providing separation assurance for all aircraft.

Technologies

Controller Workstations

- As defined in Section 2.3.2

Unequipped Aircraft

- As defined in Section 2.3.4.2

Equipped Aircraft

- As defined in Section 2.3.4.1

Standard Operating Procedures

- ATSP maintains separation responsibility for all managed aircraft
- ATSP attempts to maintain lateral trajectories (for managed aircraft) by first considering speed and altitude changes
- Autonomous aircraft are responsible for maintaining separation from other aircraft and airspace hazards
- ATSP may not issue clearances/instructions to autonomous aircraft except for terminal airspace entry
- Autonomous aircraft are responsible for meeting their RTAs (± 15 seconds) and are expected to stay on their 4D trajectories
- ATSP may only cancel autonomous operations by exception (e.g., if an autonomous aircraft is off its RTA)
- RTA and speed advisories are automatically up-linked to arriving autonomous aircraft
- Traffic conflicts are resolved by following the rules-of-the-road
- Autonomous aircraft are free to modify 4D trajectories without consulting the ATSP
- Autonomous aircraft may request cancellation of autonomous operations at any time (if complying to standard ATC handoff rules)

- Cancellation of autonomous operations must be approved by the ATSP
- Equipped aircraft with autonomous control canceled remain under control of the ATSP until ATSP clears the aircraft to resume control (either by request or concurrence)
- Autonomous aircraft may request ATC assistance (for conflict resolution, flow control, and traffic management considerations)
- ATSP is expected to assist the flight crew of autonomous aircraft with request (if request are received in a timely manner)
- ATSP may point out potential traffic conflicts to autonomous aircraft (time and workload permitting)
- ATSP may cancel autonomous control if a conflict with a managed aircraft cannot be resolved otherwise
- All aircraft fly FMS Transition in TRACON
- ATSP assigns spacing interval and lead aircraft upon entry into terminal airspace
- Equipped aircraft have the authority to reject spacing assignment

2.3.7.4 Summary of Modes of Operations

Table 2 and 3 summarizes the equipment and tools available to the flight crews and ATSPs for each mode of operation.

Table 2. Aircraft Equipment for Modes of Operation.

Aircraft Equipment	Baseline	CE 6 & 11 Trajectory Negotiation		CE 5 & 11 Free Maneuvering	
	All Aircraft	*Unequipped*	*Equipped*	*Unequipped*	*Equipped*
FMS	x	x	x	x	x
RTA		x	x	x	x
CDTI	x	x	x	x	x
ADS-B	x	x	x	x	x
CPDLC		x	x	x	x
Conflict detection			x		x
Route planning			x		x
Precision descent procedure		x	x	x	x
Arrival spacing capability		x	x	x	x
Rules-of-the-road					x

Table 3. ATSP Tools for Modes of Operation.

ATSP Tools	Baseline	CE 6 & 11 Trajectory Negotiation	CE 5 & 11 Free Maneuvering
TMA	x	x	x
Descent Advisory		x	x
Conflict detection		x	x
Trial planning		x	x
Arrival spacing capability		x	x
Control exchange capability		x	x
Rules-of-the-road			x

2.3.8 Rules-Of-The-Road

A set of flight rules was developed to define the responsibilities and actions of aircraft involved in traffic conflicts. These rules apply to situations involving autonomous aircraft and, thus, are in effect only during the *DAG-TM Free Maneuvering (CE 5 & CE 11)* mode of operation. The rules-of-the-road are specific to the different types of airspace, as described below.

2.3.8.1 En Route Airspace

Aircraft normally will be separated during en route operations by flying a correct altitude for direction of flight.

Flight Levels (FL) below 290:

- On headings of 360° to 179° (i.e., eastbound), aircraft must fly at odd numbered altitudes or FL (e.g., 170, 190, 210).
- On headings of 180° to 359° (i.e., westbound), aircraft must fly at even numbered altitudes or FLs (e.g., 180, 200, 220).

FLs 290 and above:

- On headings of 360° to 179° (i.e., eastbound), aircraft must fly the following odd numbered altitudes or FLs – 290, 330, 370, etc.
- On headings of 180° to 359° (i.e., westbound), aircraft must fly the following odd numbered altitudes or FLs – 310, 350, 390, etc.

The general rule for encounters between two aircraft (at least one being under autonomous control) is that the right-of-way is determined by flight priority:

- All arriving aircraft, which are within 200 nm of their arrival airport, will have the right-of-way over all other aircraft, except emergency. (The arrival status will be indicated on CDTI and ATC displays.)

If the encounter is between two aircraft with equal priority (e.g., between two arriving aircraft or two en route aircraft) and both are in cruise, the right-of-way is based on the following rules:

- The aircraft not flying the correct altitude for direction of flight will maneuver.

- For encounters between aircraft that are flying the correct altitude for direction of flight, the aircraft on the right will have the right-of-way.

In situations when aircraft of equal priority are climbing, descending, or overtaking, the following rules apply:

- For encounters between climbing or descending aircraft and an aircraft in level flight, the aircraft in level flight will have the right-of-way.
- For encounters between a climbing and a descending aircraft, the descending aircraft will have the right-of-way.
- For two aircraft climbing or descending, the aircraft on the right will have the right-of-way.
- For encounters where one aircraft is overtaking another on the same path (approx. 20° or less), the lead aircraft will have the right-of-way.

In addition, any aircraft may agree to cede the right-of-way to another aircraft at any time. The en route airspace rules-of-the-road apply only to encounters in which autonomous aircraft are involved. Resolution of conflicts between managed aircraft is the discretion of the ATSP. For encounters between managed and autonomous aircraft, the ATSP applies these rules on behalf of the managed aircraft.

2.3.8.2 Terminal Airspace

All aircraft are under ATSP control. There is no free maneuvering or trajectory change requests allowed.

2.3.8.3 Transitioning Between En Route and Terminal Airspace

All aircraft are required to meet an RTA for the initial transition from en route to terminal airspace. If an autonomous aircraft fails to meet its RTA, the low altitude en route controller (Bowie) may cancel autonomous operations and control the aircraft so as to provide an acceptable flow to the TRACON.

2.3.9 Scenario Description

Four traffic scenarios were developed for the simulation. Each 60-minute scenario depicts a DFW arrival push. Traffic density is medium to heavy, with approximately 90 aircraft per scenario. The scenarios, having similar characteristics and parameters, are considered equivalent in traffic flow and complexity. One scenario will be used during the training runs and the other three during data collection runs. The three data collection scenarios are designated DAG 1, DAG 2, and DAG 3.

Scenario events include handling conflicts, routing DAL arrivals through DFW arrivals, merging aircraft into an arrival stream in Bowie, and coping with traffic-load delays in the arrival flow. Approximately 40 aircraft are involved in conflicts that have been built into the scenario. However, due to the dynamic nature of the airspace, many more or many fewer conflicts may occur when the scenarios are run with a full complement of controllers and pilots. Winds will be consistent across all scenarios.

The three data collection scenarios are described in the following paragraph and in Table 4. The scenarios are set in the northwestern section of ZFW airspace and depict a single-gate arrival flow of approximately 7 minutes in-trail.

Table 4. Summary of Traffic Scenarios Used for Data Collection.

Parameter	Traffic Scenario		
	DAG 1	DAG 2	DAG 3
Total number of aircraft	88	94	87
Number of arrivals	46 (42 + 1 NASA UKW7, 4 DAL)	50 (47 UKW7, 3 DAL)	45 (42 UKW7, 2 DAL)
Number of departures	14	13 (12 DFW, 1 DAL)	13 (12 DFW, 1 DAL)
Number of over-flights	28	31	30
Arrival traffic flow	From northwest, north, and northeast to DFW	Same	Same
Arrival	UKW7 (via Heatr, Ganja, SPS, Moose) GREGS4	Same	Same
Departure traffic flow	Mostly to the north through Ardmore	Same	Same
Departure	TEX7	Same	Same
Over-flight traffic flow	- Start east of DFW center going to west - Start southwest of DFW center going to northeast - Start southeast of center going to northwest	Same	Same
Sector load	44 Amarillo, 47 Wichita Falls, 75 Bowie, 48 Ardmore, 248 TRACON, 50 Ghost North, and 93 Ghost South	Same	Same
Insertion point of aircraft	Mostly in Ghost sectors for those aircraft that get initialized late in scenario	Same	Same
Frequency of delays	High at end of scenario	Low	Moderate
Conflicts	Approximately 30-40 aircraft involved	Same	Same
Aircraft type	Standard jets 737, F100, 747, 757, A320, etc.	Same	Same
Suggested order of running	Third	First	Second

The majority of aircraft arrive into DFW, flying the UKW7 STAR, through the northwest cornerpost and landing on runways 13R and 18R. In addition, there are several northbound departures that exit the scenario through Ardmore and Ghost North, and over-flights from the south, east, and west. There are four aircraft on the GREGS4 STAR to DAL RW13L. These flights have to cross the DFW UKW arrival flow. Tables 5, 6, and 7 identify the flights (including their originating sector and radio frequency) that will be flown by the subject pilots during each scenario. Appendix D shows the test matrix for each PCPlane flight deck station during the data collection runs.

Table 5. Identification of ACFS and PCPlane Aircraft for Scenario DAG 1.

Simulator Type	Simulator Name	Flight ID	Station Number	Begins in Sector (#)	Frequency
ACFS	ACFS	NASA 2	NA	Amarillo (44)	127.85
PCPlane	A 1	AAL492	26	Amarillo (44)	127.85
	A 2	COA4562	31	Amarillo (44)	127.85
	A 3	AAL851	19	Ghost North (50)	135.45
	A 4	AAL444	35	Ghost South (93)	120.77
	SJSU	AAL136	45	Amarillo (44)	127.85
	Rotorcraft	AAL508	22	Ghost South (93)	120.77

Table 6. Identification of ACFS and PCPlane Aircraft for Scenario DAG 2.

Simulator Type	Simulator Name	Flight ID	Station Number	Begins in Sector (#)	Frequency
ACFS	ACFS	NASA 3	NA	Ghost North (50)	135.45
PCPlane	A 1	COA2070	38	Amarillo (44)	127.85
	A 2	AAL1773	46	Ghost North (50)	135.45
	A 3	DLH151	47	Ghost North (50)	135.45
	A 4	FDX931	40	Ghost South (93)	120.77
	SJSU	COA1183	41	Ghost South (93)	120.77
	Rotorcraft	AAL908	42	Amarillo (44)	127.85

Table 7. Identification of ACFS and PCPlane Aircraft for Scenario DAG 3.

Simulator Type	Simulator Name	Flight ID	Station Number	Begins in Sector (#)	Frequency
ACFS	ACFS	NASA 6	NA	Amarillo (44)	127.85
PCPlane	A 1	COA4562	31	Amarillo (44)	127.85
	A 2	UAL1027	48	Ghost North (50)	135.45
	A 3	AAL850	37	Ghost North (50)	135.45
	A 4	UAL222	49	Amarillo (44)	127.85
	SJSU	AAL508	36	Amarillo (44)	127.85
	Rotorcraft	AAL1028	50	Ghost North (50)	135.45

2.4 Experimental Design

2.4.1 Independent Variable

The only independent variable in the present study will be the mode of operation (Table 8), as described in Section 2.3.1. The study will therefore use a single-factor design, which will vary along three levels. The conditions will be designated as follow:

Table 8. Independent Variable.

Condition	Mode of Operation
Base	Baseline (Section 2.3.7.1)
CE 6	Trajectory Negotiating and In-Trail Spacing (Section 2.3.7.2)
CE 5	Free Maneuvering and In-Trail Spacing (Section 2.3.7.3)

According to the proposed experimental plan, shown in Table 9, three runs will be held on a daily basis. Each day, participants will complete a run in one of the three scenarios for each of the three operational conditions (Days 1, 2 and 3 are scheduled training days). By the end of the study, participants will have completed at least one run in each condition with each traffic scenario. The presentation order of the three modes of operation and the three scenarios will be counterbalanced in order to reduce the likelihood of a learning bias.

Table 9. Presentation of Conditions and Scenarios for Data Collection Runs.

Day 4	Day 5	Day 6	Day 7
Condition/Scenario	Condition/Scenario	Condition/Scenario	Condition/Scenario
CE6/DAG 3	Base/DAG 2	CE6/DAG 1	CE5/DAG 3
Base/DAG 2	CE5/DAG 1	Base/DAG 3	CE6/DAG 2
CE5/DAG 1	CE6/DAG 3	CE5/DAG 2	Base/DAG 1

2.4.2 Dependent Variables

Several measures will be collected during the experimental runs. Dependent variables will include human performance metrics and system-level metrics. Subjective, or self-reported data will be gathered with a series of questionnaires that will be administered after simulation runs. More precisely, participants will complete flight crew or controller post-run questionnaires after every experimental run. At the end of the study, they will complete flight crew or controller post-simulation questionnaires. Objective measures will be collected via the simulation software recordings. The following two sections provide a description the human performance metrics and a list of the system performance metrics.

2.4.2.1 Human Performance Metrics

Demographic Information

A background questionnaire is presented in the appendix. This questionnaire will be used to gather demographic information and the level and type of experience of participants (controllers and pilots).

Workload

Subjective workload assessments will be collected from controllers and pilots using the Air Traffic Workload Input Technique (ATWIT) (Stein, 1985). Controllers will be required to rate their workload via WAKs on a scale of 1 to 7, at 4-minute intervals throughout each simulation run. Participants will also complete a modified version of the NASA-Task Load Index (TLX) after every run. Questions from the NASA-TLX will be included in the controller and pilot post-run questionnaires. Other questions in the post-run questionnaires will ask participants if they felt that they had sufficient time to allocate to communication and coordination tasks. In addition to self-reports, researchers will make over-the-shoulder observations of controller actions. Measures of task workload, such as the number of aircraft in a sector, which is mentioned in the performance metrics section, will also be collected.

Communications

During the experimental runs, the simulation software will record ground-to-air (and air-to-ground), air-to-air, and ground-to-ground communications.

Usability

Post-run and post-simulation questionnaires will address usability issues with the advanced technologies. Participants will indicate if they found their tools to be effective and usable. Participants will also answer questions regarding the adequacy of the procedures and rules-of-the-road used during the simulation runs and will be encouraged to make improvement suggestions, if they have any. Post run data analysis software will also calculate the number of entries made by users.

Acceptability

Questions regarding the acceptability of the tools, procedures, and the rules-of-the-road used during the simulation will be asked during the post-run and post-simulation questionnaires. Another option would consist in using the Controller Acceptance Rating Scale (CARS) (Lee, Kerns, Bone, & Nickelson, 2001).

2.4.2.2 System Performance Metrics

The simulation software will record and compute measures reflecting system capacity, complexity, efficiency, and safety. These system level metrics are listed in Table 10 along with the relevant stakeholder.

Table 10. System Performance Metrics.

Metric	System Level				Stakeholder		
	Capacity	Complexity	Efficiency	Safety	En Route Controller	TRACON Controller	Flight Crew
Average distance traveled by aircraft (sector/overall)			x		x	x	x
Average time aircraft spent under control of each sector controller	x		x		x	x	
Average deviation from FMS flight plan		x	x				x
Average deviation from assigned spacing interval			x				x
Average actual time of arrival (ATA) spacing at meter fix	x		x		x		
ATA spacing at final approach fix (FAF)	x		x			x	
Average altitude deviation from crossing restriction at the meter fix		x	x	x	x		x
Number of FMS flight plan amendments		x	x		x		x
Number of altitude changes			x		x	x	x
Number of heading changes			x		x	x	x
Number of speed changes			x		x	x	x
Total delay: $\sum$(ATA – STA)	x		x		x	x	
Number of aircraft holds		x	x		x	x	x
Average deviation from STA			x		x		x
Number of controller cancellations of autonomous control		x		x	x		x
Number of pilot cancellations of autonomous control		x		x	x		x
Number of conflict alert warnings				x	x	x	x
Closest point of approach (CPA) for aircraft pairs that were in conflict alert				x	x	x	x
Number of operational errors*/LOS				x	x	x	x
Number, proportion, and nature of pilot-controller voice communications							
Number, proportion, and nature of data-linked clearances							
Number of aircraft in sector every 5 minutes	x	x			x	x	
Number of altitudes used	x	x			x	x	
Number of aircraft at each altitude	x	x			x		
Handoff latency*				x	x	x	
Average number of entries for flight plan modification			x		x		x

* Indicates metric might not be available

2.4.3 Research Questions and Relevant Metrics

This section lists several basic research questions to be answered in this study. Questions are grouped according to the area of focus – system level, ATC, and FD. Questions are further arranged according to question type (e.g., performance, safety, and workload). Listed below each research question are the metrics (from the two previous sections) that will be used to help answer the question.

2.4.3.1 System Level

Performance

Question: Does one mode of operation result in more efficient operations?
Metrics:
- Average distance traveled by aircraft
- Average time aircraft spent under control of sector controller
- Average deviation from FMS flight plan
- Average ATA spacing at meter fix
- Average ATA spacing at FAF
- Average altitude deviation from crossing restriction at the meter fix
- Number of flight plan, altitude, heading, and speed changes

Question: Is one mode of operation better at reducing arrival delay?
Metrics:
- Total delay: $\sum(ATA - STA)$
- Average distance traveled by aircraft
- Number of aircraft holds

Question: Is one mode of operation better at conforming to the arrival schedule?
Metrics:
- Average deviation from the scheduled time of arrival (STA)

Question: Are the rules-of-the-road effective for resolving traffic conflicts? (CE 5 condition only)
Metrics:
- Number of controller cancellations of autonomous control
- Number of pilot cancellations of autonomous control
- Post-simulation questionnaire
- Debriefings

Safety

Question: Are all three modes of operation safe according to established standards?
Metrics:
- Number of conflict alert warnings
- Closest point of approach (CPA) for aircraft pairs in conflict
- Number of operational errors*/LOS

Question: Is it clear who is responsible for resolving the traffic conflict? (CE 5 condition only)
Metrics:
- Over-the-shoulder observations
- Debriefing

Communications

Question: Does pilot-controller communication differ between the modes of operation?
Metrics:
- Number, proportion, and nature of pilot-controller voice communications
- Number, proportion, and nature of data-linked clearances

Question: Does controller-controller communication differ between modes of operation?
Metrics:
- Number, proportion, and nature of controller-controller voice communications

Experimental Validity

Question: Do the three traffic scenarios provide comparable traffic flow problems?
Metrics:
- Number of aircraft in sector every 5 minutes
- Number of altitudes used
- Average distance traveled by aircraft
- Average ATA spacing at meter fix
- Average ATA spacing at FAF
- Traffic scenario descriptions
- ATWIT

Question: Are the traffic flow rates high enough to test the operational concepts?
Metrics:
- Number of aircraft in sector every 5 minutes
- Average ATA spacing at meter fix
- Average ATA spacing at FAF
- Total delay: $\sum(\text{ATA} - \text{STA})$
- Number of altitudes used
- Number of aircraft at each altitude
- ATWIT

Simulation fidelity

Question: Do traffic scenarios contain realistic traffic flows (i.e., a mix of arrivals, departures, over-flights, jets, and turbo-props flying credible routes)?
Metrics:
- Traffic scenario descriptions
- Post-simulation questionnaire
- Debriefings

Question: Is the behavior of the pseudo-pilots/aircraft sufficiently realistic that controllers did not need to adapt their strategies to compensate for limitations they observed?
Metrics:
- Post-run questionnaire
- Debriefings

2.4.3.2 Air Traffic Control

Performance

Question: Is controller performance affected by the mode of operation?
Metrics:
- Number of operational errors* (between managed/managed or managed/autonomous aircraft)
- CPA for aircraft pairs in conflict
- Post-run questionnaire

Workload

Question: Is controller workload affected by the mode of operation?
Metrics:
- ATWIT
- NASA-TLX (post-run questionnaire)
- Number of flight plan, altitude, heading, and speed changes
- Average time aircraft spent under control of sector controller
- Number of aircraft in sector every 5 minutes
- Number of altitudes used
- Number of aircraft at each altitude
- Number of aircraft holds
- Handoff latency*

Acceptability

Question: Do controllers find each of the three modes of operation acceptable?
Metrics:
- Number of controller cancellations of autonomous control (CE 5 condition only)
- Post-simulation questionnaire
- Debriefings

Question: Do controllers find the rules-of-the-road acceptable? (CE 5 condition only)
Metrics:
- Post-simulation questionnaire
- Debriefings

Usability

Question: Does any component of the interface interfere with controller task performance?
Metrics:
- Post-simulation questionnaire
- Debriefings

2.4.3.3 Flight Deck (PCPlane)

Performance

Question: Are pilots capable of flying their FMS flight plans in each mode of operation?
Metrics:
- Average deviation from FMS flight plan

Question: Are pilots capable of maintaining their assigned spacing interval within terminal airspace?

Metrics:
- Average deviation from assigned spacing interval (CE 6 & 5 conditions only)

Workload

Question: Is pilot workload affected by the mode of operation?
Metrics:
- NASA-TLX (post-run questionnaire)
- Number of flight plan, altitude, heading, and speed changes
- Average number of entries for flight plan modification

Safety

Question: Are pilots capable of operating safely within each mode of operation?
Metrics:
- Number of LOSs
- CPA for ownship and intruder

Acceptability

Question: Do pilots find each of the three modes of operation acceptable?
Metrics:
- Number of pilot cancellations of autonomous control (CE 5 condition only)
- Post-simulation questionnaire
- Debriefings

Question: Do pilots find the rules-of-the-road acceptable? (CE 5 condition only)
Metrics:
- Post-simulation questionnaire
- Debriefings

Usability

Question: Does any component of the interface interfere with pilot task performance?
Metrics:
- Post-simulation questionnaire
- Debriefings

* Indicates metric might not be available

2.5 Participant Training

The purpose of training is to ensure that all participants are familiar with the tools, display, procedures and rules-of-the-road that will be used during the experiment. The more proficient participants are with these items, the more their performance will emulate operational conditions, and the more representative the results will be. Prior to participating in data collection runs, pilot and controller subject participants will be trained on the DAG-TM concepts and the tools they will use in the simulation. Training will be broken into three phases and take place over a period of three days. The training schedule is outlined in Table 11.

Phase 1

The first phase will include all subject participants. As a group, the pilots and controllers will attend a DAG-TM orientation consisting of a description of the experiment objectives, terminology unique to the study, and detailed descriptions of the concept elements to be studied. Specific differences between CE 5 and CE 6 experimental conditions will be discussed thoroughly.

Subject participants will be provided with a description of the basic scenarios that will be used in the simulation, including information on the airspace and traffic flows, arrival and approach charts, and precision descent information. The pilots and controllers will be provided with a brief description of the tools that will be available and the rules-of-the-road.

Presenting this background information to the pilots and controllers as a group will help both groups understand the roles, responsibilities, and procedures of the other group. Because DAG-TM relies on distributed decision-making and close understanding of roles, this exchange of information will be valuable in facilitating this understanding and should enhance the overall success of the simulations.

Phase 2

After the initial orientation, pilots and controllers will be divided into separate training groups. This second phase of the training will focus on user-specific instruction on the tools and procedures unique to both groups.

The controllers that will be participating in the study will have all previously participated in DAG-TM simulations and therefore will be familiar with the concepts, terminology, and procedures. However, any changes in the displays, tools and procedures since the previous simulation will be discussed.

The pilot subject participants, however, will all be new to the DAG-TM experience. To ensure that the pilots are at the same level of proficiency as controllers, researchers have prepared a training packet that focus on both the concepts and the tools required for participation in distributed air-ground traffic management. Researchers will provide the pilots with an overview of the CEs, and the symbology specific to each CE. Details regarding the displays, controls, and procedures for each CE and baseline condition will be presented. The training packet will include screen shots of the CSD and diagrams of the relevant alerting symbology. The screen shots will show what steps are required for specific procedures and what the results are of selected control interactions. A section specific to PCPlane use, including communications, datalink, and FMS usage, will also be included.

Phase 3

The final phase of training will consist of a distributed simulation where each subject and support participant will be at his or her station, and all participants will complete several training runs as a group. The scenarios for the training runs will be designed specifically for training and will not be used during any of the data collection runs. However, the training runs will still be conducted in the Dallas-Ft. Worth airspace with traffic flow and airspace constraints similar to those that will be found in the data runs. Trained observers will be permitted to provide coaching to the participants as necessary during the training runs.

3. Data Collection and Analysis

3.1 September 2002 Schedule

Training and data collection will occur over a two week time period. Table 11 contains a schedule for the September DAG-TM research study. It includes a training schedule, 18 data collection runs, time slots for questionnaires and debriefings, and travel time for participants.

Table 11. Training and Data Collection Schedule – Week 1.

<table>
<tr><th></th><th>Monday
9/9/2002</th><th>Tuesday
9/10/2002</th><th>Wednesday
9/11/2002</th><th>Thursday
9/12/2002</th><th>Friday
9/13/2002</th></tr>
<tr><td>8:00</td><td rowspan="11">Travel Day for Participants</td><td rowspan="2">Introduction to DAG-TM</td><td>Briefing</td><td>Briefing</td><td>Briefing</td></tr>
<tr><td>8:30</td><td rowspan="2">CE 5 Training Run</td><td rowspan="2">Baseline Training Run</td><td>Check-in</td></tr>
<tr><td>8:45-10:00</td><td>Break</td><td>Data Collection Run 1</td></tr>
<tr><td>10:00</td><td rowspan="3">Experiment Briefing (CE 6, CE 5, CE 11, airspace, rules-of-the-road)</td><td>Break</td><td>Break</td><td>Break</td></tr>
<tr><td>10:15</td><td rowspan="2">Baseline Training Run</td><td rowspan="2">CE 6 Training Run</td><td>Check-in</td></tr>
<tr><td>10:30-11:45</td><td>Data Collection Run 2</td></tr>
<tr><td>12:00-1:00</td><td>Lunch</td><td>Lunch</td><td>Lunch</td><td>Lunch</td></tr>
<tr><td>1:00</td><td rowspan="2">Introductory Simulator Training</td><td rowspan="2">Debriefing</td><td rowspan="2">CE 5 Training Run</td><td>Check-in</td></tr>
<tr><td>1:15-2:30</td><td>Data Collection Run 3</td></tr>
<tr><td>2:30</td><td>Break</td><td>Break</td><td>Break</td><td>Break</td></tr>
<tr><td>3:00-4:00</td><td>CE 6 Training Run</td><td>CE 6 Training Run</td><td>Debriefing</td><td>Debriefing</td></tr>
</table>

Table 12. Training and Data Collection Schedule – Week 2.

	Monday 9/16/2002	**Tuesday** 9/17/2002	**Wednesday** 9/18/2002	**Thursday** 9/19/2002	**Friday** 9/20/2002
8:00	Briefing	Briefing	Briefing	Briefing	Travel Day for Participants
8:30	Check-in	Check-in	Check-in	Check-in	
8:45-10:00	Data Collection Run 4	Data Collection Run 7	Data Collection Run 10	Repeat Data Collection Run (if needed)	
10:00	Break	Break	Break	Break	
10:15	Check-in	Check-in	Check-in	Post-experiment questionnaire	
10:30-11:45	Data Collection Run 5	Data Collection Run 8	Data Collection Run 11		
12:00-1:00	Lunch	Lunch	Lunch	Lunch	
1:00	Check-in	Check-in	Check-in	Check-in	
1:15-2:30	Data Collection Run 6	Data Collection Run 9	Data Collection Run 12	Demonstration Run	
2:30	Break	Break	Break	Break	
3:00-4:00	Debriefing	Debriefing	Debriefing	Debriefing	

3.2 Data Analysis

All data collection will lead to detailed descriptive analyses and when appropriate, to inferential tests using a repeated-measures design, in order to determine if the mode of operation will have had an effect on the different dependent variables examined.

For example, ATWIT ratings will be graphically depicted according to each participant, function (i.e., ARTCC or TRACON controller, or pilot), scenario, and mode of operation. A one-way analysis of variance (ANOVA) could be performed, if assumptions regarding variable distribution, level of measurement, and sample size are respected, in order to determine if the mode of operation had an effect on the average workload rating. However, because of the small number of subjects (n=1) and restrictions typical of large-scale simulation studies, assumptions such as random sampling, independence of observations, and homogeneity of variance will not hold. Using a nonparametric test such as the randomization test will be more appropriate. Another nonparametric test, such as the Friedman test, could also be used to determine if the distribution of the workload ratings differ in the three operational conditions (or in other words, if the ratings varied in a similar way during each run across the three modes of operation).

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APPENDIX

A. Acronym List

ACFS	Advanced Concepts Flight Simulator
ADRS	Aeronautical Datalink and Radar Simulator
ADS-B	Automatic Dependent Surveillance-Broadcast
AOC	Airline Operations Center
AOL	Airspace Operations Lab
ARAT	Advanced Route Analysis Tool
ARC	Ames Research Center
ARTCC	Air Route Traffic Control Center
ATA	Actual Time of Arrival
ATC	Air Traffic Control
ATM	Air Traffic Management
ATMSDI	Air Traffic Management System Development and Integration
ATSP	Air Traffic Service Provider
ATWIT	Air Traffic Workload Input Technique
CARS	Controller Acceptance Rating Scale
CE	Concept Element
CDTI	Cockpit Displays of Traffic Information
CNS	Communication, Navigation, and Surveillance
CPA	Closest Point of Approach
CPDLC	Controller Pilot Data Link Communication
CSD	Cockpit Situation Display
CTAS	Center TRACON Automation System
CVSRF	Crew Vehicle Systems Research Facility
DA	Descent Advisor
DAG-TM	Distributed Air/Ground Traffic Management
DAL	Love Field Airport
DFW	Dallas/Forth Worth Airport
DST	Decision Support Tool
ETA	Estimated Time of Arrival
FAF	Final Approach Fix
FANS	Future Air Navigation System

FD	Flight Deck
FL	Flight Level
FMS	Flight Management System
GA	General Aviation
LNAV	Lateral Navigation
MACS	Multi Aircraft Control System
MCP	Mode Control Panel
LOS	Loss Of Separation
NAS	National Airspace System
NASA	National Aeronautics and Space Agency
PAS	Primary Alerting System
pFAST	passive Final Approach Spacing Tool
PFD	Primary Flight Display
PGUI	Plan-View Graphical User Interface
RTA	Requested Time of Arrival
SOP	Standard Operating Procedure
STA	Scheduled Time of Arrival
TCAS	Traffic Alert & Collision Avoidance System
TFM	Traffic Flow Management
TLX	Task Load Index
TMA	Traffic Management Advisor
TRACON	Terminal Radar Approach Control
WAK	Workload Assessment Keyboard
VCR	Video Cassette Recorder
VNAV	Vertical Navigation
VNAV	Vertical Navigation
ZAB	Albuquerque ARTCC
ZFW	Forth Worth ARTCC
ZKC	Kansas City ARTCC

B. DFW Arrival Charts

For Simulation Use Only

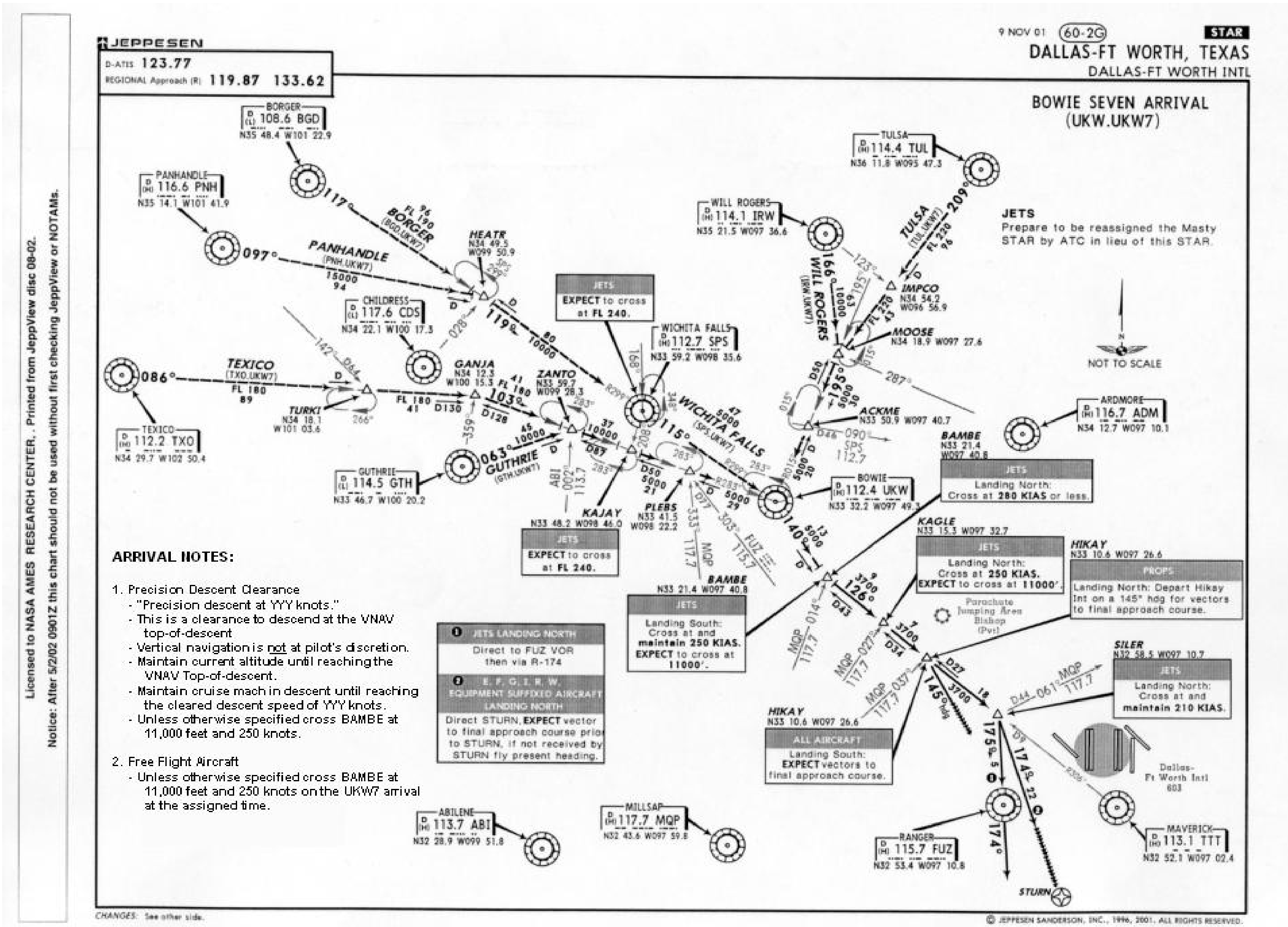
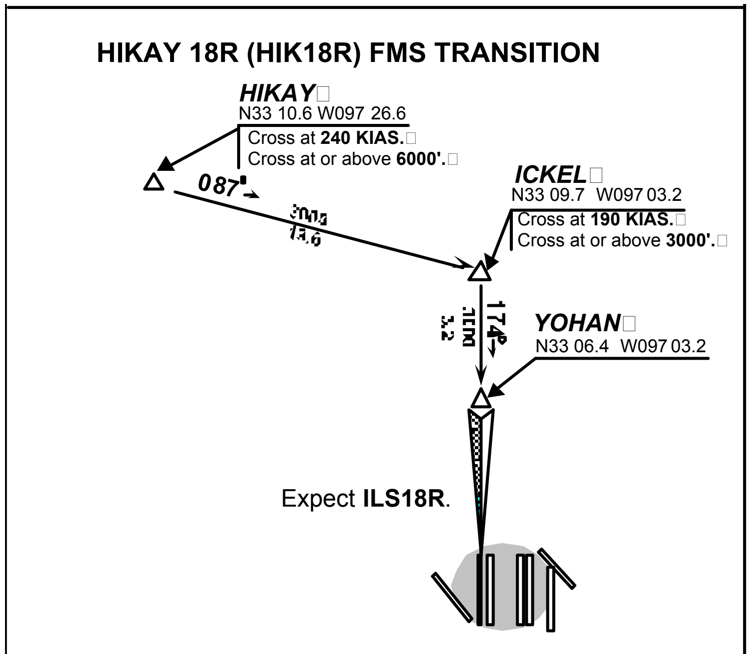


Figure 8. Bowie Seven Arrival (UKW7).

For Simulation Use Only

HIKAY 18R (HIK18R) FMS Transition

	Distance	Altitude	Speed
BAMBE	50.7nm	11,000′	250
KAGLE	41.7nm	-----	---
HIKAY	34.6nm	6,000′	240
ICKEL	15.0nm	3,000′	190
YOHAN	11.8nm	3,000′	170
HASTY	5.2nm	2,200′	150
18R	0.0nm	591′	---



HIKAY 13R (HIK13R) FMS Transition

	Distance	Altitude	Speed
BAMBE	41.1nm	11,000′	250
KAGLE	32.1nm	-----	---
HIKAY	25.0nm	6,000′	240
MORRY	12.9nm	3,000′	210
POPPA	7.9nm	3,000′	170
GUUDE	5.4nm	2,200′	150
13R	0.0nm	591′	---

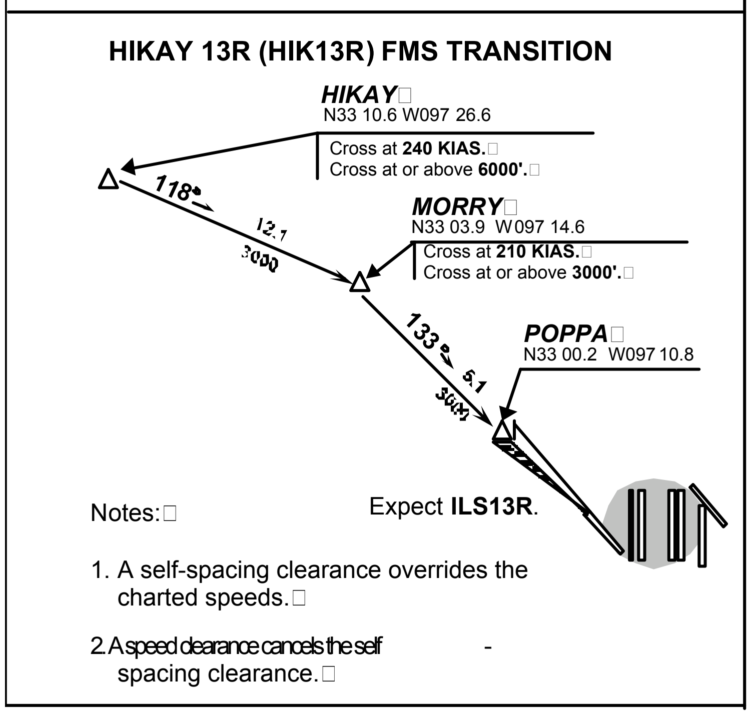
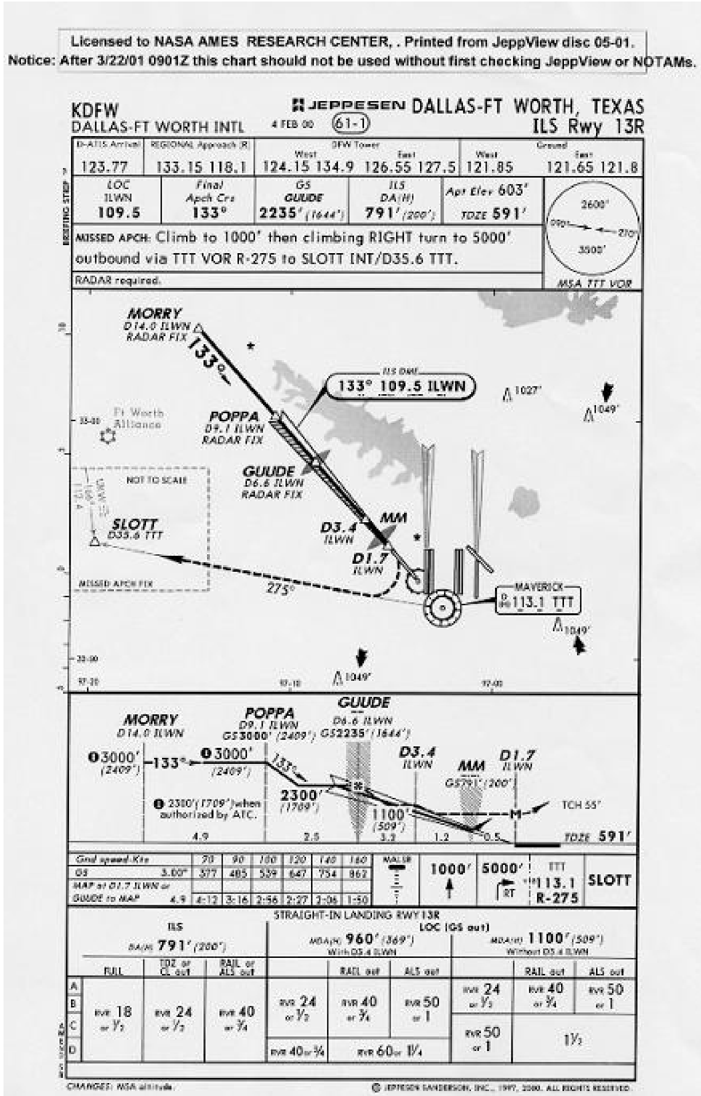


Figure 9. HIKAY 13R & 18R FMS Transitions.

For Simulation Use Only



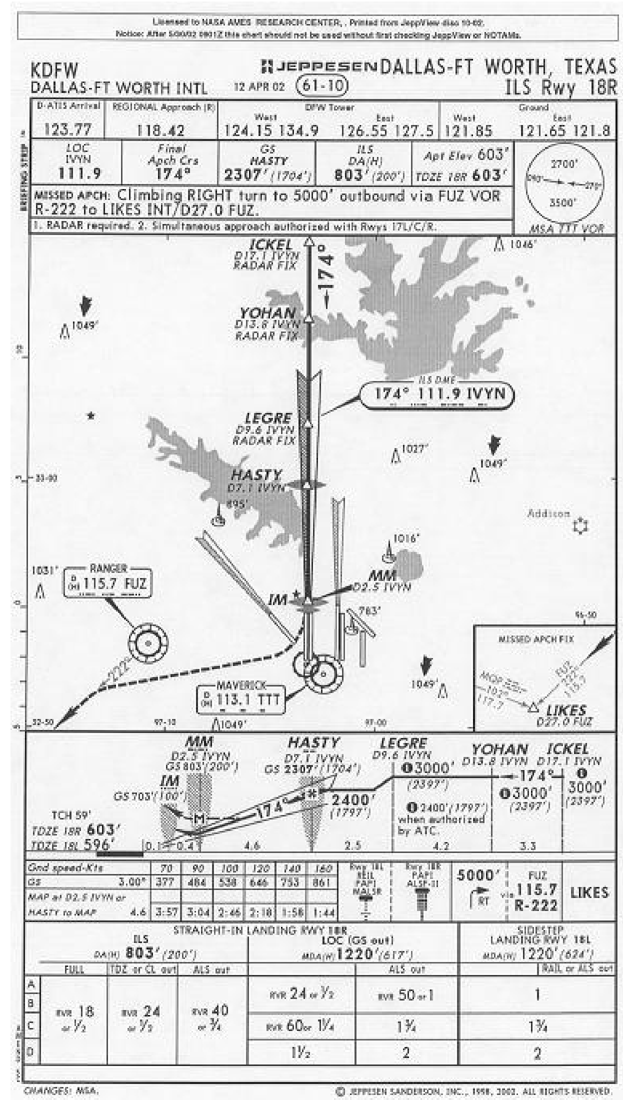


Figure 10. KDFW ILS Rwy 13R & 18R Approach Charts.

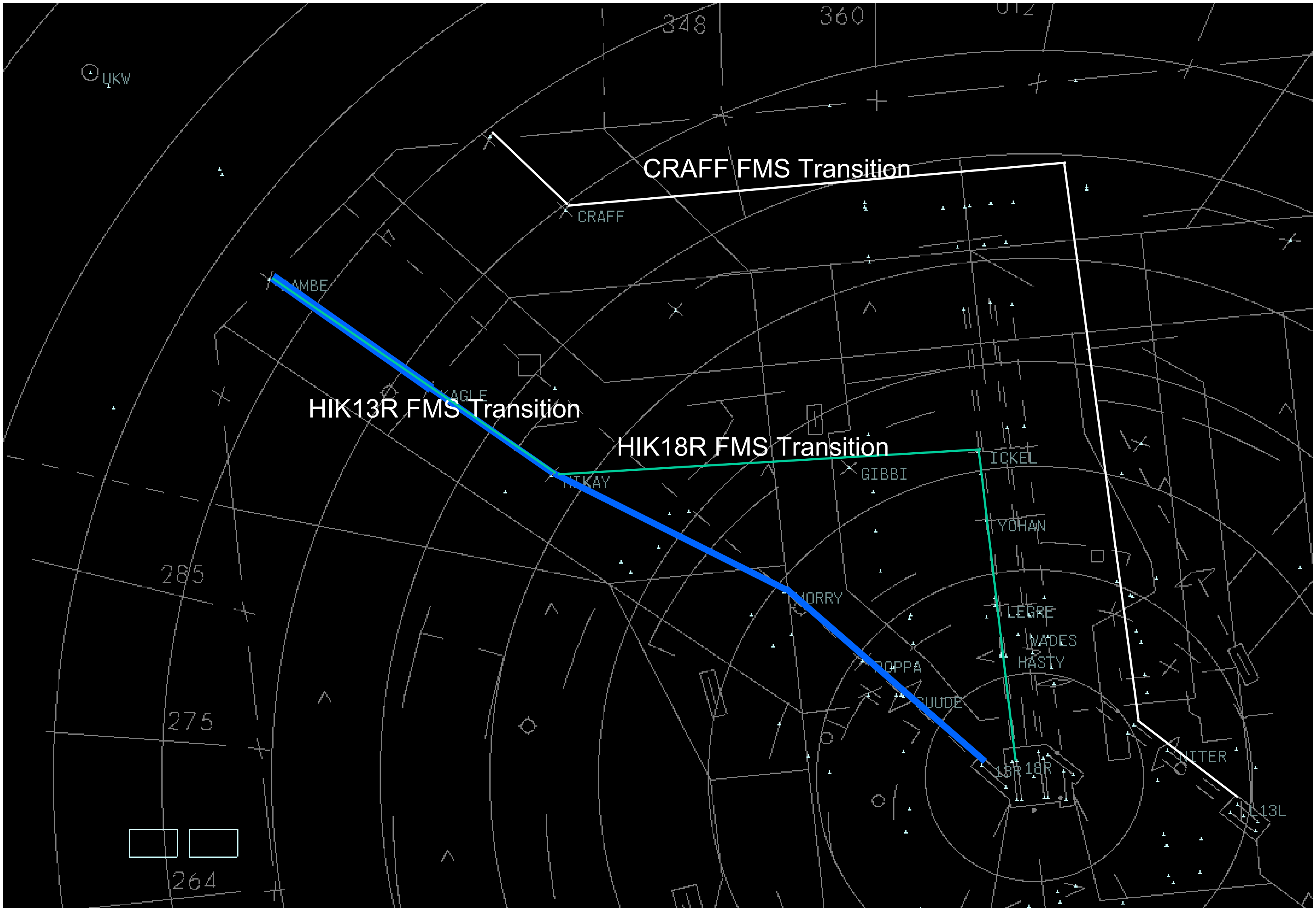


Figure 11. DFW TRACON Airspace.

For Simulation Use Only

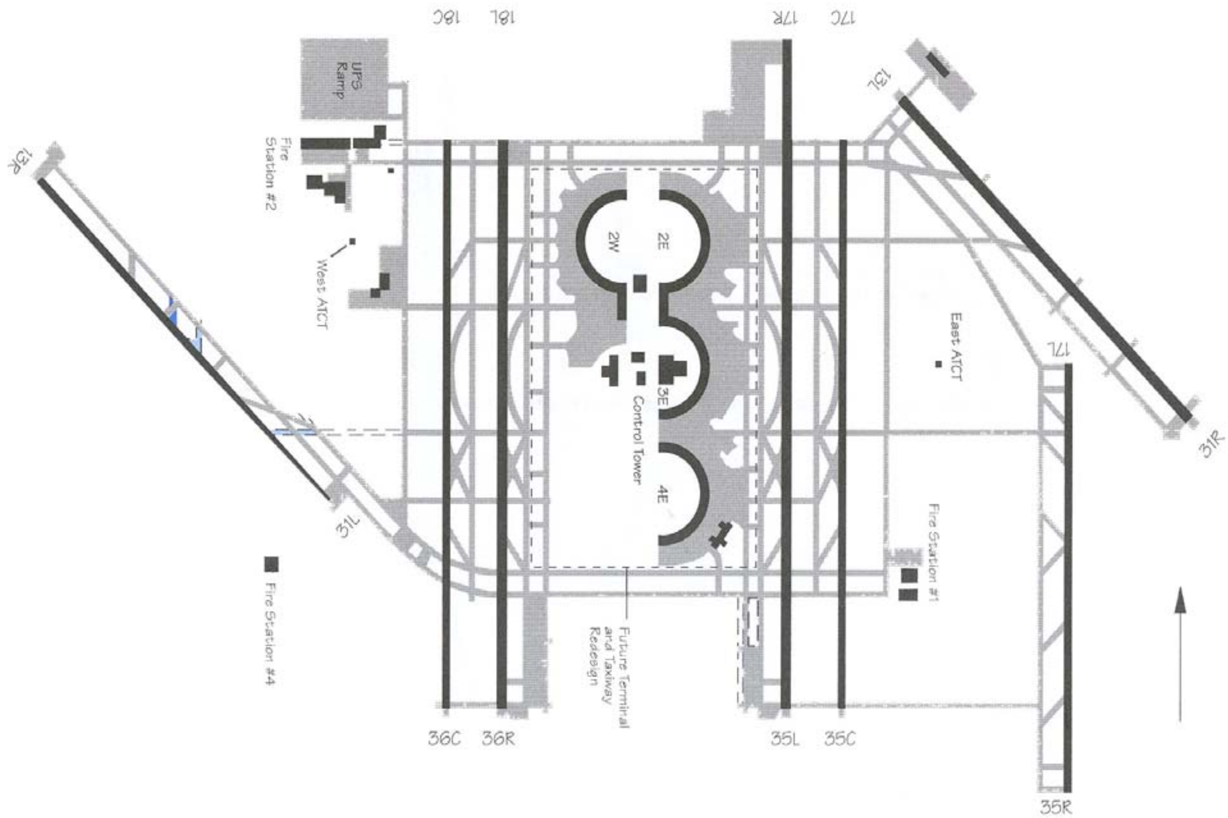


Figure 12. DFW Surface Map.

C. Precision Descent Clearance Phraseology

Normal clearance:
"Cleared for a precision descent at YYY knots."

Expected pilot behavior:
On receipt of the precision descent clearance the pilot is expected check that the crossing restriction BAMBE is 11,000 feet and 250 knots, enter 0.XX/YYY on the VNAV descent page, lower the MCP altitude to 11,000 feet and engage VNAV. (0.XX is the cruise Mach.)

Clearance with an altitude limit:
"Cleared for a precision descent at YYY knots except maintain flight level 240."

Expected pilot behavior:
On receipt of the precision descent clearance the pilot is expected check that the crossing restriction BAMBE is 11,000 feet and 250 knots, enter 0.XX/YYY on the VNAV descent page, lower the MCP altitude to 24,000 feet and engage VNAV. (0.XX is the cruise Mach.)

Controller expectations for a normal precision descent clearance:
Aircraft will maintain current lateral routing
Aircraft will maintain cruise altitude and Mach until its VNAV top of descent.
Aircraft will initiate descent at its VNAV top-of-descent point.
Aircraft will descend at cruise Mach until reaching the assigned descent speed and then maintain the assigned descent speed.
Aircraft will maintain assigned descent speed within plus/minus 10 knots.
Aircraft will cross BAMBE at 11,000 feet and 250 knots.

D. Flight Deck Station Test Matrix

Table 13. Flight Deck Station Test Matrix with Flight IDs.

Date	Run	Condition/ Scenario	FD Station (PCPlane)						ACFS
			A1	A2	A3	A4	SJSU	Rotorcraft	
Friday Sept. 13	1	CE6 DAG 3	AAL1028 (50)	COA4562 (31)	UAL1027 (48)	AAL850 (37)	UAL222 (49)	AAL508 (36)	NASA 6
	2	Base DAG 2	FDX931 (40)	COA1183 (41)	AAL908 (42)	COA2070 (38)	AAL1773 (46)	DLH151 (47)	NASA 3
	3	CE5 DAG 1	AAL136 (45)	AAL508 (22)	AAL492 (26)	COA4562 (31)	AAL851 (19)	AAL444 (35)	NASA 2
Monday Sept. 16	4	Base DAG 2	DLH151 (47)	FDX931 (40)	COA1183 (41)	AAL908 (42)	COA2070 (38)	AAL1773 (46)	NASA 3
	5	CE5 DAG 1	COA4562 (31)	AAL851 (19)	AAL444 (35)	AAL136 (45)	AAL508 (22)	AAL492 (26)	NASA 2
	6	CE6 DAG 3	COA4562 (31)	UAL1027 (48)	AAL850 (37)	UAL222 (49)	AAL508 (36)	AAL1028 (50)	NASA 6
Tuesday Sept. 17	7	CE6 DAG 1	AAL851 (19)	AAL444 (35)	AAL136 (45)	AAL508 (22)	AAL492 (26)	COA4562 (31)	NASA 2
	8	Base DAG 3	UAL1027 (48)	AAL850 (37)	UAL222 (49)	AAL508 (36)	AAL1028 (50)	COA4562 (31)	NASA 6
	9	CE5 DAG 2	COA2070 (38)	AAL1773 (46)	DLH151 (47)	FDX931 (40)	COA1183 (41)	AAL908 (42)	NASA 3
Wednesday Sept. 18	10	CE5 DAG 3	UAL222 (49)	AAL508 (36)	AAL1028 (50)	COA4562 (31)	UAL1027 (48)	AAL850 (37)	NASA 6
	11	CE6 DAG 2	COA1183 (41)	AAL908 (42)	COA2070 (38)	AAL1773 (46)	DLH151 (47)	FDX931 (40)	NASA 3
	12	Base DAG 1	AAL508 (22)	AAL492 (26)	COA4562 (31)	AAL851 (19)	AAL444 (35)	AAL136 (45)	NASA 2

E. Experimenter Tasking

Table 14. Experimenter Tasking and Points of Contact.

Task		Points of Contact
Simulation coordinator		Tom Prevot
Procedures (transitioning, etc.)		Ev Palmer
Rules-of-the-road		Vern Battiste, Tom Prevot
Metrics	AOL	Paul Lee
	FD	Walt Johnson
Training materials	AOL	Nancy Smith
	FD	Steve Shelden
Questionnaire	AOL	Nancy Smith
	FD	Paul Mafera
Observer form	AOL	Sandy Lozito
	FD	Nancy Johnson
WAK implementation	AOL	Nancy Smith
Participant scheduling	AOL	Nancy Smith
	FD	Vern Battiste
Pseudo-pilot training		Joey Mercer
Scenario testing / debugging		Savvy Verma
Room scheduling		Nancy Smith
AOL audio & video recording		Nancy Smith
IRB form		Sandy Lozito
Test plan documentation		Paul Mafera
Software Development	TRACON DSTs	Ev Palmer
	Center DSTs	Tom Prevot
	IHI CTAS	Tom Prevot
	ADRS	Tom Prevot
	MACS	Tom Prevot
	CTAS data analysis	Todd Callantine
	ACFS data analysis (CATS)	Todd Callantine
	CSD	George Lawton, Mohammad Refai, Dominic Wong
Remote flight deck stations		Steve Shelden
PCPlane flight deck observer (A1)*		John Moses

PCPlane flight deck observer (A2)*	Paul Mafera
PCPlane flight deck observer (A3)*	JF D'Arcy
PCPlane flight deck observer (A4)*	Mike Montalvo
Observer at remote flight deck station – SJSU	Nancy Johnson
Observer at remote flight deck station – Rotorcraft	Bill Cunliffe
ACFS observer	Katja Helbing

* Positions in the Ames Flight Deck Display Lab